MULTIPLE DETERMINANTS OF THE EFFECTS OF REINFORCEMENT MAGNITUDE ON FREE-OPERANT RESPONSE RATES

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Four experiments examined the effects of increasing the number of food pellets given to hungry rats for a lever-press response. On a simple variable-interval 60-s schedule, increased number of pellets depressed response rates (Experiment 1). In Experiment 2, the decrease in response rate as a function of increased reinforcement magnitude was demonstrated on a variable-interval 30-s schedule, but enhanced rates of response were obtained with the same increase in reinforcement magnitude on a variable-ratio 30 schedule. In Experiment 3, higher rates of responding were maintained by the component of a concurrent variable-interval 60-s variable-interval 60-s schedule associated with a higher reinforcement magnitude. In Experiment 4, higher rates of response were produced in the component of a multiple variable-interval 60-s variable-interval 60-s schedule associated with the higher reinforcement magnitude. It is suggested that on simple schedules greater reinforcer magnitudes shape the reinforced pattern of responding more effectively than do smaller reinforcement magnitudes. This effect is, however, overridden by another process, such a contrast, when two magnitudes are presented within a single session on two-component schedules.

Key words: reinforcement magnitude, variable-interval schedules, variable-ratio schedules, concurrent schedules, multiple schedules, response shaping, contrast, lever press, rat

Increases in reinforcement magnitude typically have been associated with greater speeds of running in an alleyway (see Mackintosh, 1974, pp. 151–159, for a review). This straightforward correspondence between manipulation of a reward parameter and behavior in the alleyway has been taken as an indication that reinforcement magnitude is a fundamental determinant of behavior (e.g., Black, 1969). Several investigators have, consequently, assumed that a similar relationship may exist between reinforcement magnitude and free-operant response rates (e.g., de Villiers, 1977; Killeen, 1985).

Experiments investigating the influence of reinforcement magnitude on free-operant response rate have, however, offered a mixed pattern of results. Some authors have reported little effect of magnitude manipulations (Keesey & Kling, 1961; Powell, 1969), whereas others have reported large and durable effects (Harzem, Lowe, & Priddle-Higson, 1978; Reed & Wright, 1988). Of those studies that have noted reliable effects, some have found a positive relationship between increases in reinforcement magnitude and response rates (e.g., Bradshaw, Szabadi, & Bevan, 1978; see de Villiers, 1977, for a review), some a negative relationship (e.g., Harzem et al., 1978), and some both increases and decreases in rate depending upon the parameters of the conditioning episode (Reed & Wright, 1988).

A number of accounts have been put forth to explain the rate-enhancing action of reinforcement magnitude on free-operant performance and to offer some suggestions as to why the manipulation of reinforcement magnitude often fails to produce this result. Some authors (e.g., Killeen, 1985) have suggested that increasing the magnitude of reinforcement increases the level of arousal of the subject, and the increased level of instrumental performance reflects the change in the level of arousal. However, a number of studies have noted both increases and decreases in instrumental performance as a result of increases in reinforce-

ment magnitude within a given situation (e.g., Hendry, 1962; Reed & Wright, 1988). This result may be thought of as incompatible with any simple version of arousal theory. Another view suggests that response rates with an increased magnitude of reinforcement will be elevated, relative to those where no increase in reinforcement magnitude occurs, due to the factors that generate contrast (e.g., Reynolds, 1961). Contrast views suggest that increased reinforcement magnitudes will increase performance only in those situations that allow contrast effects to develop. This may be why magnitude effects occur more readily when magnitude is manipulated within, rather than between, sessions (e.g., Harzem, Lowe, & Davey, 1975; Schrier, 1958). However, it is by no means clear that, even when increased magnitudes occur in close temporal proximity to smaller magnitudes of reinforcement, performance levels increase (see Harzem et al., 1978). Alternatively, a notion that may be termed a response-contingency view (Neuringer, 1967) suggests that reinforcement magnitude will exert a greater influence on response rate when the contingency between responding and obtained reinforcement magnitude is stronger rather than when it is weaker. Thus, when a subject can choose a higher magnitude of reinforcement, responses for that alternative will increase relative to when a subject has no control of the obtained reinforcement magnitude. This latter notion has the advantage of proposing reasons why some studies obtain an effect (e.g., Catania, 1963) and some studies do not (e.g., Keesy & Kling, 1961). Although this view is more easily applied to two-component situations than to the single schedule, it is possible to suggest that on schedules with a weak relationship between, say, rate of response and rate of reinforcement, magnitude of reinforcement will have little effect on response rate.

Although it is possible that some (or all) of the above factors operate to determine the influence of reinforcement magnitude, the confused state of the pattern of results obtained from this manipulation in free-operant studies is a hindrance to understanding the action of this parameter. Specifically, it is not clear that increases in reinforcement magnitude always lead to increases in performance unless some other factor operates to prevent the occurrence of this rate enhancement. For example, studies by Harzem et al. (1978) have noted decreases in response rate as a result of increases in reinforcement magnitude. In a study that attempted to clarify the confused state of findings related to free-operant schedules of reinforcement, Reed and Wright (1988) demonstrated that the effect of reinforcement magnitude on instrumental performance may not be simply that increased magnitudes of reinforcement produce increased levels of performance unless other factors cancel out the effect. Rather, the effect of reinforcement magnitudes was found to be dependent on the schedule of reinforcement in operation. On a variable-ratio (VR) schedule, increases in magnitude of reinforcement enhanced response rates; in contrast, on a differential-reinforcement-of-low-rate (DRL) schedule, increases in magnitude of reinforcement attenuated response rate.

The schedule dependency of reinforcement magnitude effects noted by Reed and Wright (1988) suggests another factor than those outlined may operate to determine reinforcement magnitude effects on free-operant instrumental performance. One possibility is that larger magnitudes of reinforcement more effectively strengthen the pattern of behavior on which they are contingent. That different magnitudes of reinforcement may support different patterns of behavior has previously been established (Carlson & Wielkiewicz, 1976; Trapold, 1970). When greater magnitudes of reinforcement are made contingent upon high rates of response, levels of performance increase (Blakely & Schlinger, 1988; Buskist, Oliveira-Castro, & Bennett, 1988; Gentry & Eskew, 1984). However, when greater reinforcement magnitudes are made contingent upon low rates of response, response rates decline (Hendry, 1962; Hendry & Van-Toller 1964). If schedules arrange reinforcement for different patterns of responding (Ferster & Skinner, 1957; Morse, 1966), then increasing the magnitude of reinforcement on those contingencies that differentially reinforce low rates of response (e.g., DRL) should produce lower levels of responding, whereas those schedules that reinforce high rates of response (e.g., VR schedules) should demonstrate a positive relationship between reinforcement magnitude and response rate.

The present report attempted to document further the effects of reinforcement magnitude on schedule performance and demonstrate

when the processes outlined above are responsible for these effects.

EXPERIMENT 1

Because variable-interval (VI) schedules have been the most widely studied schedule with respect to reinforcement magnitude effects, the present experiment was designed to clarify the effect of increasing the reinforcement magnitude (defined as increasing the number of food pellets per reward), between sessions, on responding maintained by a VI schedule. A number of studies have noted increasing the concentration of a particular reinforcer will lead to higher rates of response on a VI schedule (Bradshaw, Ruddle, & Szabadi 1981; Guttman, 1953; see also de Villiers, 1977, for a review). However, those studies of reinforcement magnitudes that have used reinforcer amounts (e.g., number of food pellets per reward) have noted no effect (e.g., Keesey & Kling, 1961). The first experiment attempted to establish the effect of increasing the number of food pellets given as reinforcers on a VI schedule with magnitude parameters known to be effective in altering response rates for rats responding on VR and DRL schedules (see Reed & Wright, 1988).

METHOD

Subjects

Four experimentally naive male Lister hooded rats, approximately 3 months old at the start of the experiment, were used. The rats were maintained at 80% of their free-feeding body weights, were housed in pairs, and had water constantly available in the home cage.

Apparatus

Four operant-conditioning chambers (Campden Instruments Ltd.), each housed in a sound- and light-attenuating case, were used. A ventilating fan provided a 65-dB(A) background masking noise. The chamber was equipped with two retractable response levers, positioned 5 cm above a grid floor and 11 cm apart. Reinforcers (consisting of 45-mg food pellets) were delivered at a rate of one per 100 ms to be a recessed magazine tray that was covered by a hinged, clear Perspex flap, located midway between the two response levers. The chamber was not illuminated during the experiment.

Procedure

The subjects were magazine trained in two 40-min sessions during which the levers were retracted from the chamber and food pellets were delivered according to a variable-time (VT) 60-s schedule (range, 3 to 180 s). During the first session of magazine training, the flap covering the magazine tray was taped open to allow easy access to the pellets. During the second session, the flap was lowered to its standard resting position. Following magazine training, the left lever was inserted into the chamber and the subjects were given two sessions during which every response was reinforced (i.e., a continuous reinforcement, CRF, schedule). Each session of CRF lasted until the subject had earned 75 reinforcers. All subjects were then given four 40-min sessions of exposure to a VI 30-s schedule (range, 2 to 90 s).

Following pretraining, all subjects responded on a VI 60-s schedule of reinforcement (range, 3 to 180 s) that remained in operation throughout the experiment. The VI 60-s schedule used here, and in all future experiments, was composed of 10 values selected equally often, by computer, to yield an average VI of 60 s. The values were 3 s, 5 s, 10 s, 25 s, 40 s, 65 s, 70 s, 82 s, 120 s, and 180 s. During Phase 1, subjects were given 20 80-min sessions of VI 60-s training, during which reinforcement consisted of the delivery of one food pellet. During Phase 2, the magnitude of reinforcement was increased to four food pellets, and this training lasted for 20 20-min sessions. Thus, the number of food pellets earned during a session in Phase 2 was approximately the same as earned during a session in Phase 1 and, hence, the satiating effects of the reinforcer were approximately equal across the sessions of the two phases. The final phase of training consisted of a return to baseline; that is, the magnitude of reinforcement was decreased to one food pellet. Phase 3 lasted for 20 80-min sessions.

RESULTS AND DISCUSSION

To maintain consistency with previous studies (e.g., Reed & Wright, 1988), results are based on the data obtained from the last six
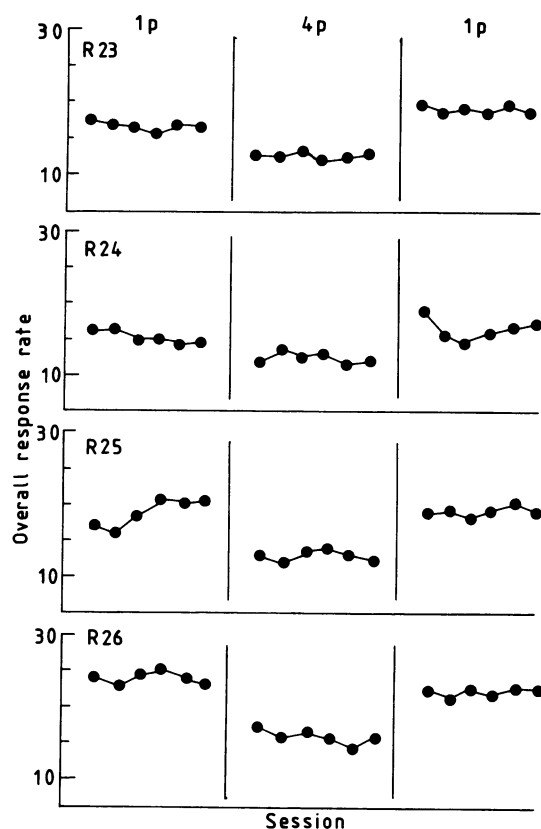
Fig. 1. Results from Experiment 1. Response rates over the final six sessions in each phase of VI 60-s training for each subject. 1p = one-pellet reinforcer, 4p = four-pellet reinforcer.

sessions in each experimental phase of the study. Despite not specifying stability criteria, the results reflect performance that did not vary during the terminal part of each phase by more than five responses per minute from session to session and are generally typical of performance over the preceding 10 to 12 sessions.

Response rates generated over the last six sessions in each reinforcement-magnitude condition are displayed in Figure 1. This measure was calculated by dividing the total number of responses made by the subject during the session by the session length. The results depicted in Figure 1 demonstrate that the higher magnitude of reinforcement in Phase 2 (i.e., four pellets) generated low response rates for 3 of the 4 subjects relative to Phase 1 (Subject R24 showing no effect). When the number of food pellets was decreased to one pellet in Phase 3,

the rate of response for the 3 animals demonstrating a decrease in Phase 2 recovered to the levels noted at the end of Phase 1. The mean response rates for the last six sessions of each phase for all 4 subjects were 18 responses per minute for the one-pellet condition in Phase1, 13 responses per minute for the four-pellet condition in Phase 2, and 19 responses per minute for Phase 3.

Figure 2 displays the response running rates for all subjects. This measure was calculated by subtracting the latency to the first response following each reinforcement from the total session time prior to calculating response rate. Inspection of these data reveals that the response running rates followed the same pattern as the overall response rates; the increase in reinforcement magnitude in Phase 2 generally resulted in a decrease in response rate. The mean scores for each phase were 20 responses per minute for the one-pellet condition in Phase 1, 16 responses per minute for the four-pellet condition in Phase 2, and 22 responses per minute for Phase 3.

The mean postreinforcement pause over the final six sessions at each reinforcement-magnitude condition is displayed in Figure 3. The postreinforcement pause was defined as the time to the first response following delivery of a reinforcer. Inspection of these data for Phases 1 and 3 reveals that small, comparable, postreinforcement pauses were generated for all subjects with a one-pellet reinforcement. Increasing the magnitude of reinforcement in Phase 2 resulted in longer postreinforcement pauses relative to Phases 1 and 3. This is consistent with previous data obtained from studies of magnitude of reinforcement on VI schedules (e.g., Harzem et al., 1978), although the present data may simply reflect increased consumption time associated with large numbers of food pellets.

Increases in the magnitude of reinforcement thus resulted in lower overall response rates, lower response running rates, and slightly longer postreinforcement pauses on a VI 60-s schedule of reinforcement. These effects of magnitude on response rate may have been due to the longer postreinforcement pause, generated by the larger magnitudes of reinforcement, producing lower overall response rates. However, the fact that response running rates were also lower with larger magnitudes of reinforcement suggests that the decrease in re-
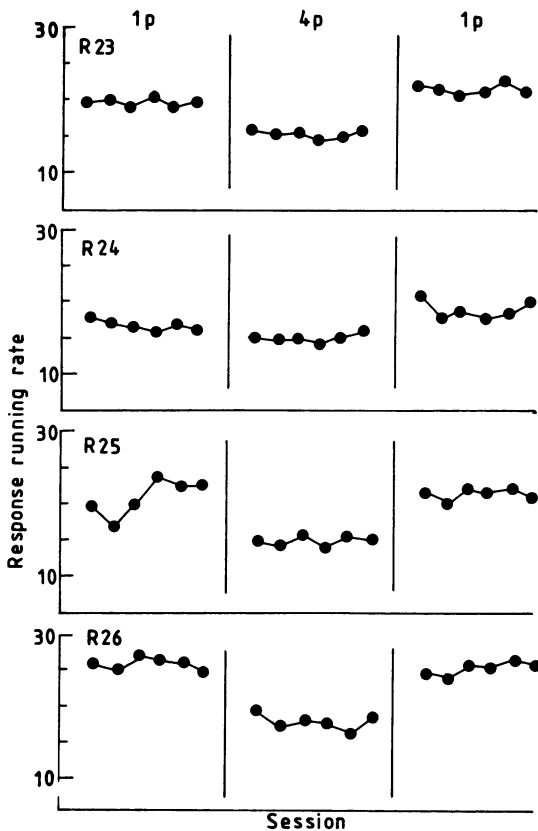
Fig. 2. Results from Experiment 1. Response running rates over the final six sessions of each phase of VI 60-s training for each subject. This score was calculated by subtracting the postreinforcement pause from the total session time prior to calculating response rate. 1p = one-pellet reinforcer, 4p = our-pellet reinforcer.
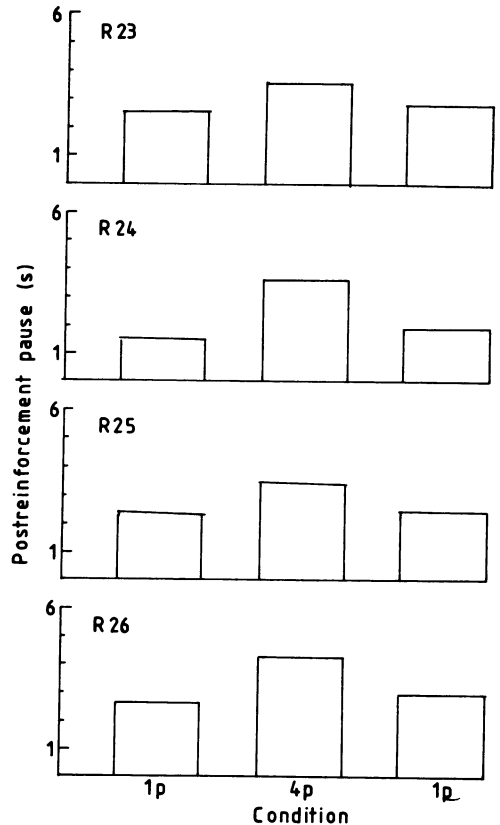

Fig. 3. Results from Experiment 1. Postreinforcement pause calculated as a mean over the last six sessions in each phase of VI 60-s training for each subject. 1p = one-pellet reinforcer, 4p = four-pellet reinforcer.

sponse rate generated by increased reinforcer amounts does not entirely reflect increases in the length of the postreinforcement pause.

EXPERIMENT 2

The results from Experiment 1 suggest a negative relationship between reinforcement magnitude and response rate on VI schedules. This stands in contrast to previous studies of reinforcer amount on VI schedules that suggest the opposite relationship (see de Villiers, 1977). However, inspection of one of these studies (Bradshaw et al., 1981) reveals that there may be an interaction between reinforcement magnitude and reinforcement frequency. Larger magnitudes of reinforcement often maintain higher response rates on lean VI schedules,

whereas this effect may be absent, or reversed, on richer VI schedules (Bradshaw et al., 1981). The range of reinforcement frequencies that produce no effect, or a negative relationship between response rate and reinforcement frequency, is that range studied in the present Experiment 1 and also in the previous studies that have used amount of reinforcer as a variable (e.g., Keesey & Kling, 1961). If reinforcement rate is a contributing factor to the effect of reinforcement magnitude manipulations, then an increase in the reinforcement frequency of the VI schedule studied should also allow the effect noted in Experiment 1 to be demonstrated.

By using a VI schedule of a richer reinforcement frequency, an opportunity is offered to compare the effect of reinforcement magnitude on VI and VR schedules that are approximately matched in terms of reinforce-

ment rate. This comparison is provoked by the finding reported by Reed and Wright (1988) that increases of reinforcement magnitude on VR 30 schedules (that produced a reinforcement frequency similar to a VI 30-s schedule) increased response rates. Should the same magnitude of reinforcement increase rates on a VR but decrease rates of response on a VI schedule of reinforcement, support will be given to the account of the action of reinforcement magnitude offered by Reed and Wright (1988) and outlined in the general introduction above.

METHOD

Subjects and Apparatus

Four experimentally naive male Lister hooded rats were used. They were 4 months old at the start of the study, had a weight range of 325 to 400 g, and were maintained as described in Experiment 1. Two of the conditioning chambers described in Experiment 1 were employed in the present study.

Procedure

The subjects were magazine trained as described in Experiment 1. The left lever was then inserted into the chamber, and the subjects received two sessions of CRF training as described in Experiment 1. Following the second session CRF training, the left lever was retracted and the right lever inserted into the chamber. Two further sessions of this CRF training were then given. Subjects were then exposed to a multiple VR VI schedule. On the first session of multiple-schedule training, the left lever was inserted into the chamber and the subjects were required to complete a VR 5 schedule (range, 1 to 10). Reinforcement was then delivered and the lever retracted. Following an interval of 3 s, the right lever was inserted into the chamber and the subject was required to complete a VI 15-s schedule (range, 1 to 45 s). When the interval criterion was satisfied, reinforcement was delivered and the lever retracted. Following an interval of 3 s, the left lever was reinserted into the chamber and the subject was exposed to the VR 5 schedule. Components were thus presented in strict alternation. Sessions lasted until the subject collected 30 reinforcers (i.e., 15 in each component). The second session of the multiple-schedule training was programmed as above, except the schedule parameters were VR 10

(range, 2 to 18) and VI 20 s (range, 1 to 60 s). For the following two sessions the criteria were increased to a multiple VR 20 (range, 4 to 36) VI 25-s (range, 2 to 75 s) schedule, and for the final two sessions of pretraining a multiple VR 25 (range, 5 to 45) VI 30-s schedule occurred. For the critical experimental phases of the experiment, subjects earned reinforcement on a multiple VR 30 VI 30-s schedule.

During Phase 1 of the critical experimental training, subjects received one food pellet on completion of each component of the multiple schedule. This phase lasted for 20 sessions. Each session lasted until the subject had earned 80 reinforcers, 40 in each component. For Phase 2, the magnitude of reinforcement earned in each component was increased to four food pellets. Phase 2 comprised 20 sessions; each session lasted until the subject had earned 20 reinforcers (i.e., 10 in each component). This manipulation ensured that equal numbers of food pellets were consumed per session in Phase 1 and Phase 2 and, hence, the satiating effects of the food reward were approximately equal for each session of Phases 1 and 2. Phase 3 consisted of a return to baseline; that is, subjects received one food pellet for satisfying each component of the multiple schedule. Each session of Phase 3 lasted until the subject had received 80 reinforcers, 40 in each component.

RESULTS AND DISCUSSION

The results are based on the last six sessions in each phase of the study. This performance was similar to the rate of responding generated on the preceding eight to 10 sessions, and individual rats showed no systematic trend in their responding during the terminal sessions of each phase.

Figure 4 displays the overall response rates emitted by all 4 subjects in both components of the multiple schedule. This measure was calculated by dividing the total number of responses emitted in a component by the total amount of time the lever associated with a component was present in the chamber. During Phase 1, subjects came to respond at a higher rate in the VR 30 component of the multiple schedule than in the VI 30-s component. The mean rate of responding for the 4 subjects over the last 6 days of Phase 1 in the VR component was 79 responses per minute compared to 26 responses per minute in the VI 30-s component. This difference in rate

is consistent with the higher rates of responding maintained by VR compared to VI schedules in previous studies (e.g., Zuriff, 1970), and may reflect the slightly higher rate of reinforcement in the VR component compared to the VI component (a mean of 2.6 reinforcers per minute in the VR component and 1.9 reinforcers per minute in the VI component).

With the larger magnitude of reinforcement during Phase 2, response rates decreased in the VI component for 3 of the 4 subjects (the exception being R30, which demonstrated no systematic effect as a result of increased reinforcement magnitude). The effect on response rates in the VR schedule, however, was not as clear. Two subjects (R27 and R30) displayed increases in response rate compared to Phase 1, Subject R29 displayed no change in response rate, and Subject R28 came to respond at a lower rate than in Phase 1. The mean response rate over these sessions for the 4 subjects in the VI component was 18 responses per minute (resulting in 1.9 reinforcers per minute) and in the VR component was 85 responses per minute (producing 2.9 reinforcers per minute); these scores represent slightly lower and higher mean rates of response than were generated during the VI and VR components of Phase 1, respectively.

Upon return to the one-pellet condition in Phase 3, response rates increased in the VI component to a level comparable with that in Phase 1 (i.e., a mean of 27 responses per minute in Phase 3). Rates in the VR component were also similar to those noted in Phase 1 (i.e., a Phase 3 mean of 82 per minute). Subjects earned 2.7 reinforcers per minute in the VR component of the schedule in Phase 3 and 2.0 reinforcers per minute in the VI component.

Figure 5 displays the response running rates emitted by the 4 subjects in both components of the multiple schedule. This score was calculated by first subtracting the latency to the first response following the insertion into the chamber of the lever associated with a particular component from the total amount of time that lever was present in the chamber before calculating response rate. Inspection of Figure 5 reveals a pattern of results similar to that described for overall response rates. Inspection of the VI component performance reveals that, relative to Phases 1 and 3, increased magnitudes of reinforcement in Phase 2 generated
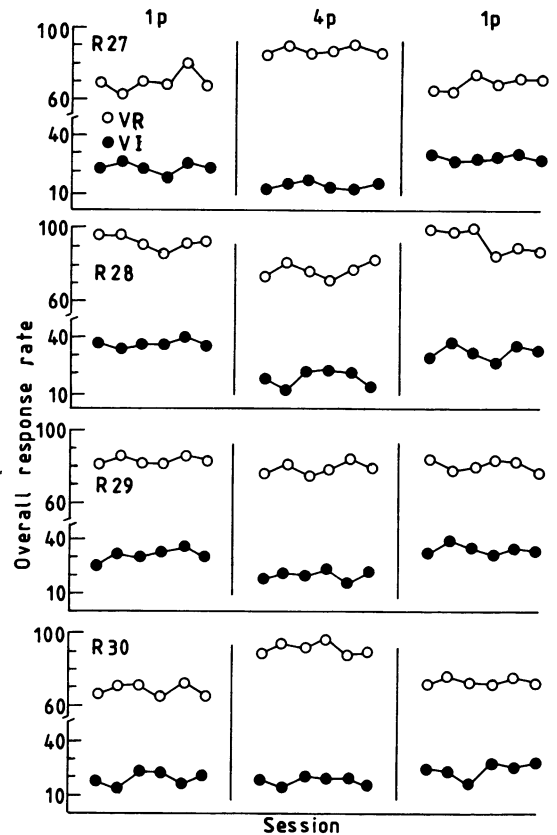

Fig. 4. Results from Experiment 2. Response rates in both components of the multiple VR 30 VI 30-s schedule over the final six sessions of each phase for each subject. VR = variable ratio, VI = variable interval, open circles = variable-ratio component, filled circles = variable-interval component, 1p = one-pellet component, 4p = four-pellet component.

low levels of responding for 3 of the 4 subjects (the exception being R30). The mean response rate of all 4 subjects in the VI component during Phase 1 was 28 responses per minute and was 20 responses per minute in Phase 2 and 29 responses per minute in Phase 3.

As with overall response rates, the increment in the magnitude of reinforcement during Phase 2 produced mixed results. In 2 of the 4 subjects, the response running rate was higher during Phase 2 than during Phases 1 and 3. The performance of Subject R28 was slightly attenuated by higher reinforcement magnitudes, and that of Subject R29 was largely unaltered by the manipulation. The mean response rate for the 4 subjects over the last six sessions of the VR component in Phase 1 was 83 responses per minute; this score increased
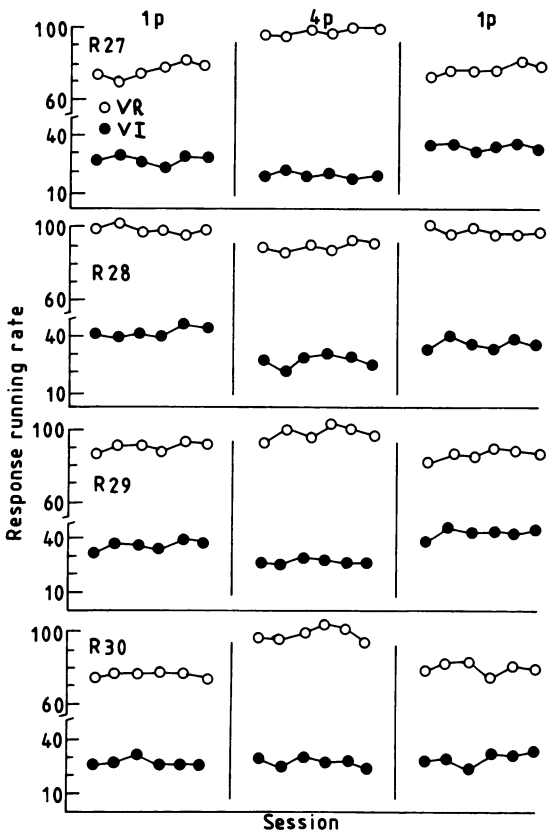
Fig. 5.   Results from Experiment 2. Response running
rates in both components of the multiple VR 30 VI 30-s
schedule over the final six sessions of each phase for each
subject. These scores were calculated by subtracting the
postreinforcement pause from the time spent in each com-
ponent prior to calculating response rate. VR = variable
ratio, VI = variable interval, open circles = variable-ratio
component, filled circles = variable-interval component,
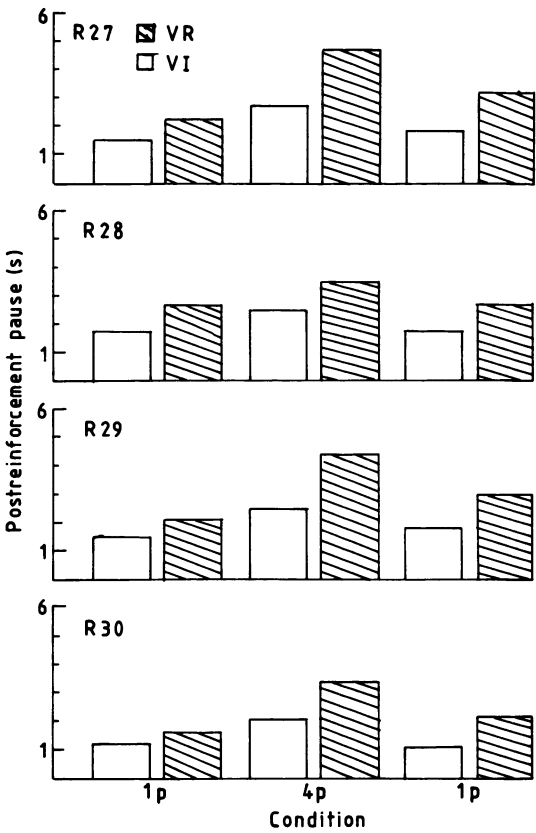1p = one-pellet component, 4p = four pellet component.

Fig. 6.   Results from Experiment 2. Postreinforcement
pause for both components of the multiple VR 30 VI 30-s
schedule calculated as a mean for the last six sessions of
each phase for each subject. VR = variable ratio, VI =
variable interval, hatched bars = variable-ratio compo-
nent, open bars = variable-interval component, 1p = one-
pellet component, 4p = four-pellet component.

to 96 responses per minute for Phase 2 and de-
creased to 85 responses per minute in Phase 3.

The mean postreinforcement pause for both
components of the multiple schedule is dis-
played in Figure 6. This score was calculated
by measuring the latency to the first response
following the insertion of the lever associated
with a particular component into the box. In-
spection of these data from Phase 1 reveals
that the postreinforcement pause was slightly
greater in the VR component than in the VI
component; however, both components gen-
erated only short pauses following the one-
pellet reinforcement. During Phase 2, with the
four-pellet reinforcement, the pause increased
in both components but was more pronounced
in the VR than in the VI schedule. It should

be noted that, as in Experiment 1, the general
increase in the postreinforcement pause may
reflect increases in consummatory time asso-
ciated with greater number of food pellets (al-
though the 3-s interval following the delivery
of food before the insertion of the lever for the
start of the next component may account for
at least some of the consumption time). In
Phase 3, with the one-pellet reinforcement, the
postreinforcement pause decreased in both
components, returning to a similar level to that
noted in Phase 1. That the postreinforcement
pause increased with larger reinforcement
magnitude to a greater extent in the VR than
in the VI schedule may have influenced the
results regarding response rates. Longer post-
reinforcement pauses associated with larger
reinforcement magnitudes may have obscured

the higher response rate once responding had commenced on the VR schedule.

This pattern of results gives some support to the notion that reinforcement may act to strengthen the pattern of responding prevailing when reinforcement is delivered (Reed & Wright, 1988). Greater magnitudes of reinforcement tended to increase responding (to the extent this is possible given that response output ceilings may exist) on a VR schedule, which may be taken to promote the emission of short interresponse times (IRTs). In contrast, increasing the magnitude of reinforcement on VI schedules may more effectively promote the emission of the typically reinforced long IRTs (e.g., Morse, 1966).

Despite this notion accounting for the present results, there are a number of findings of increased rate as a results of greater reinforcement magnitudes that are not easily accommodated by this view (e.g., Bradshaw et al., 1981; Guttman, 1953). There are at least two possible explanations for the difference in results obtained in the above studies compared to the present Experiment 2. First, it may be that manipulations of concentration of the reinforcer used by Bradshaw et al. (1981) reflect a qualitative change in reward, rather than a quantitative change in reinforcer magnitude. Such a difference in the parameter manipulation may be responsible for differences in the result obtained. Second, the previous studies have noted increases in response rate as the result of increased reinforcement magnitude on lean VI schedules of reinforcement, rather than on the rich VI schedules studied here. According to Herrnstein (1974), there may well be a ceiling effect on responding on rich VI schedules due to the insensitivity of the k parameter, which increasing the reinforcement magnitude cannot overcome. Such a ceiling effect would not exist on leaner schedules, and increasing the reinforcement magnitude may, for reasons yet to be specified (see de Villiers, 1977, for some discussion), increase the rate of response. Although this consideration implies that increasing the reinforcement magnitude should not increase rates of response on rich VI schedules, an attenuation of response rates could still be observed.

EXPERIMENT 3

A further group of reports have demonstrated that the rate of response on a VI schedule increases as the magnitude of reinforcement increases (e.g., Catania, 1963). One difference between this group of reports and the present Experiments 1 and 2 is that the former studies employed concurrent schedules, whereas the present studies used a single schedule. Another difference is the manner in which reinforcer amount was defined. Catania (1963), for example, used the time of access to a grain reinforcer in pigeons, but the present experiments used the number of food pellets in rats. It is possible that this difference in reinforcement magnitude could lead to apparently discrepant results (cf. Bradshaw et al., 1981). Experiment 3, therefore, attempted to replicate the earlier effects with a concurrent VI VI schedule using the reinforcer and species employed in the present Experiments 1 and 2.

METHOD

Subjects and Apparatus

Four experimentally naive male Lister hooded rats were used. They were 3 months old, had a free-feeding weight range of 335 to 415 g, and were maintained as described in Experiment 1. The apparatus was that described in Experiment 1.

Procedure

The subjects were magazine and lever-press trained as described in Experiment 2. Following the last CRF session, both levers were inserted into the chamber, and all subjects received two 40-min sessions of a concurrent VI 30-s VI 30-s schedule. Reinforcement in each component was controlled by an independent VI schedule.

During the first critical experimental phase, subjects responded on a concurrent VI 60-s VI 60-s schedule. Reinforcement for responding in each of the components was one food pellet. Phase 1 lasted for 20 40-min sessions. Following this training, reinforcement for one lever was increased to four food pellets. Reinforcement for the other lever remained unaltered (i.e., one food pellet). The component that received the increase in reinforcement was the component that maintained the lower rate of response in Phase 1. Phase 2 consisted of 20 30-min sessions. The final phase of training was a return to baseline in which subjects received one food pellet in both components of the schedule. This phase of training lasted for 20 40-min sessions.
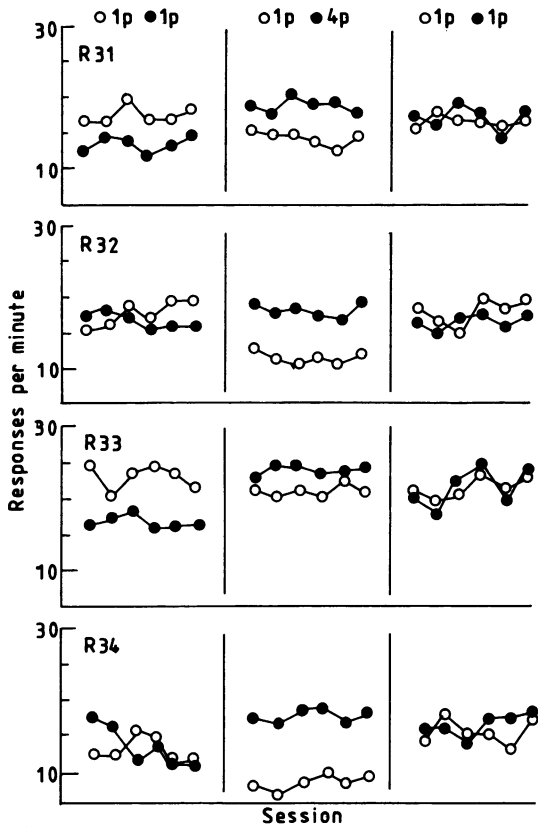
Fig. 7.   Results from Experiment 3. Response rates for both components of the VI 60-s VI 60-s concurrent schedule for the last six sessions in every phase for each subject. Open circles = unshifted component, filled circles = shifted condition, 1p = one-pellet reinforcer, 4p = four-pellet reinforcer.

RESULTS AND DISCUSSION

The results are based on the data from the last six sessions of each phase of the study. Although no stability criteria were adopted, the subjects displayed no systematic trend in their performance during the terminal sessions of the phase, and this terminal performance reflects the behavior over the preceding 10 to 13 sessions of training.

Figure 7 displays the overall response rates in both components of the schedule over the course of the experiment. Examination of the data reveals that Subjects R32 and R34 responded at comparable levels on both levers, but Subjects on R31 and R33 developed a preference for one lever. On the introduction of the Phase 2 contingencies, response rates in the shifted component came to be higher than those in the nonshifted component for all sub-

jects. For Subjects R31 and R34 this consisted of greater levels of responding, compared to Phase 1, in the component now associated with the larger magnitude of reinforcement and a decrease in the response rate in the one-pellet reinforcer component. Subject R33 displayed an increase in response rate, relative to Phase 1, in the four-pellet component but no change in levels of responding for the one-pellet component. Subject R32 displayed little change in performance in the component with the larger reinforcer, but a pronounced decrease in responding was observed for the one-pellet component. On return to the baseline condition in Phase 3, response rates in the two components for each subject became similar but were not necessarily equivalent to the rate in Phase 1. The mean response rate for subjects during the last six sessions in Phase 1 were 15 responses per minute in the to-be-shifted component and 17 responses per minute in the component that was not to experience an increase in reinforcement magnitude. In Phase 2, the mean response rate for the shifted component was 18 responses per minute, and the mean response rate for the unshifted component was 13 responses per minute. Over the last six sessions of the return to baseline, the mean response rate was 16 responses per minute in both the previously shifted and previously unshifted components.

Increasing the magnitude of food reinforcement for one component of a concurrent VI 60-s VI 60-s schedule produced a relative increase in the level of responding compared to the other component. Although the data obtained in the present study did not reflect completely stable performance, in general the results are consistent with previous findings regarding the effect of reinforcement magnitude on concurrent schedules that have varied the time of access to grain (e.g., Catania, 1963). The question remains, therefore, why the concurrent procedure should generate increases in response rate, but increases in the magnitude of reinforcement on a simple VI schedule with the present parameters result in a decrease in response rate.

EXPERIMENT 4

It is possible that manipulation of reinforcement magnitude in a concurrent schedule allows the subjects to experience two different magnitudes within a session and produces ef-

fects (i.e., contrast) not observed when the magnitude of reinforcement is altered between sessions on a simple schedule (cf. Mackintosh, 1974, pp. 354–371). An alternative view is proposed by Neuringer (1967), who suggested that the contingency between behavior and the magnitude of reinforcement is a critical factor in producing the response-rate enhancement associated with higher magnitudes of reinforcement. If the subject's choice leads to higher or lower magnitudes of reinforcement, then the contingency between the choice response and the obtained reinforcement magnitude will exert a large influence on behavior. However, when the reinforcement magnitude is presented irrespective of the subject's behavior, then there will not be a direct relationship between reinforcement magnitude and performance.

These two possibilities are confounded in a concurrent schedule but can be separated by using a multiple schedule. In a multiple schedule two components are presented within a session, but at any one time there is only one alternative available and the subject's behavior will not determine the type of reinforcer obtained. According to Neuringer (1967), similar effects of reinforcement magnitude should be noted in multiple and single schedules, because for both types of schedule the subject's behavior does not itself directly influence the magnitude of reinforcement obtained as it does in a situation that allows a choice between different magnitudes. A different prediction is derived according to the contrast notion. If two magnitudes of reinforcement are experienced within a session, as occurs in a multiple schedule, then rates of response should be higher in the component with the greater magnitude of reinforcement.

METHOD

Subjects and Apparatus

Four experimentally naive male Lister hooded rats were used. They were 4 months old at the start of the study, had a weight range of 275 to 330 g, and were maintained as described in Experiment 1. Two or the conditioning chambers described in Experiment 1 were employed in the present study.

Procedure

Initial magazine and CRF training was as described in Experiment 2. Following this training, subjects were exposed to a multiple VI 30-s VI 30-s schedule of reinforcement for two sessions. During these sessions, the left lever was inserted into the chamber and the subject was required to complete a VI 30-s schedule. Reinforcement was then delivered, and the lever was retracted. Following an interval of 3 s, the right lever was inserted into the chamber and the subject was again required to complete a VI 30-s schedule. When the interval criterion was satisfied, reinforcement was delivered and the lever retracted. Following an interval of 3 s, the left lever was reinserted into the chamber and the subject was again exposed to the VI 30-s schedule associated with the left-lever component. Components were thus presented in strict alternation. The session consisted of 30 reinforcers, 15 for each component.

For the critical experimental phases of the experiment, subjects earned reinforcement on a multiple VI 60-s VI 60-s schedule. During Phase 1, subjects received one food pellet on completion of each component of the multiple schedule. This phase lasted for 20 sessions. Each session lasted until the subject had earned 80 reinforcers, 40 in each component. For Phase 2, reinforcement earned in one component was increased to four food pellets and reinforcement in the other component was unchanged (i.e., one food pellet). The component chosen to receive the increased reinforcement magnitude was the component that supported the lower response rate in Phase 1. Phase 2 consisted of 20 sessions and each session lasted until the subject had earned 32 reinforcers, 16 in each component. This manipulation ensured that equal numbers of food pellets were consumed per session on Phase 1 and Phase 2, thereby equating the satiating effects of the food for these two phases. Phase 3 consisted of a return to baseline; that is, subjects received one food pellet for satisfying each component of the multiple schedule. Each session of Phase 3 lasted until the subject had received 80 reinforcers, 40 in each component.

RESULTS AND DISCUSSION

The results are based on the last six sessions in each phase of the study. The measures presented in the figures were calculated as described in Experiment 2. Subjects' performance did not vary by more than five responses per minute during any of the terminal sessions of each phase, and although no stability cri-
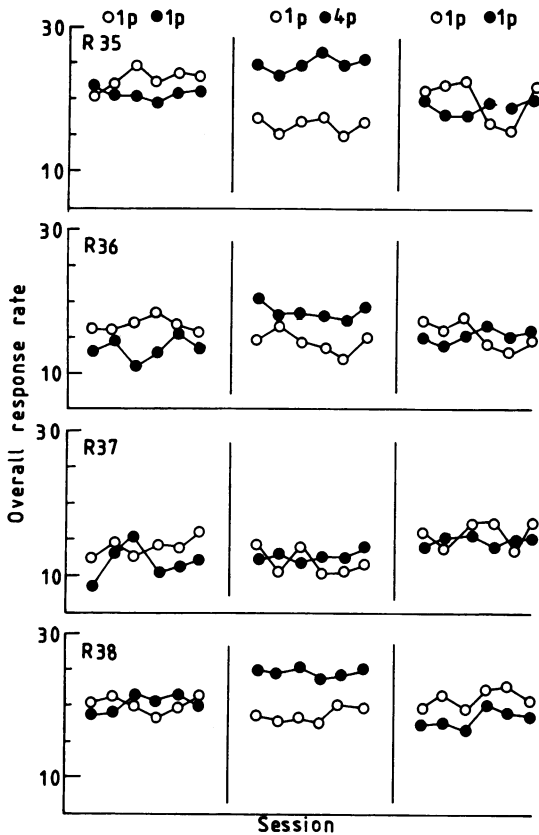
Fig. 8. Results from Experiment 4. Response rates in both components of the multiple VI 60-s VI 60-s schedule over the final six sessions of each phase for each subject. Open circles = unshifted component, filled circles = shifted component, 1p = one-pellet component, 4p = four-pellet component.

teria were adopted, the data are representative of the preceding seven to 10 sessions.

Figure 8 displays the overall response rates emitted by all 4 subjects in both components of the multiple schedule during all three phases of the experiment. Inspection of Figure 8 reveals that, during Phase 1, subjects came to respond at similar rates in both components of the multiple schedule. The mean response rate for the to-be-increased component was 16 responses per minute, and the corresponding score for the unchanged component was 19 responses per minute.

The effect of increasing the magnitude of reinforcement on responding can be seen by comparing the performance during Phases 1 and 3 with that during Phase 2. In Phase 2 it is apparent that, for 3 of the 4 subjects, response rates in the component with the greater

magnitude of reinforcement were higher than rates in the unshifted component. For Subject R35, rates in the shifted component increased from their Phase 1 levels and rates in the unshifted component deceased. For Subjects R36 and R38, the difference in response rates was a result of an increase in rate in the shifted component while response rate in the unshifted component remained unchanged from Phase 1 levels. Subject R37 demonstrated no systematic change in response rate as a result of this manipulation. The mean response rate over the final six sessions during the shifted component was 22 responses per minute compared to a mean response rate in the unshifted component of 15 responses per minute. Upon return to the baseline condition, response rates became similar in both components for all subjects but were not necessarily equivalent to the rates observed in Phase 1. The mean response rates were 17 responses per minute in the previously shifted component and 18 responses per minute in the unshifted component.

Figure 9 displays the response running rates emitted by all 4 subjects in both components of the multiple schedule for all three phases of the experiment. Inspection of Figure 9 reveals that the pattern of results was similar to that for overall response rates displayed in Figure 8. Increased reinforcement magnitude resulted in higher rates of response for 3 of the 4 rats (the exception being Subject R37). However, it should be noted that, when the postreinforcement pause was excluded from the calculation of response rate, it was clear that the difference in response rate between the components in Phase 2 was the result of an increase in response rate in the shifted component. The mean running response rate was 20 responses per minute in both components during Phase 1; these means were largely unaltered in Phase 3, the scores being 19 responses per minute in both components. However, during Phase 2 the mean rate in the increased magnitude component rose to 25 responses of per minute, compared to a rate of 18 responses per minute in the constant component.

The mean postreinforcement pause for both components of the multiple schedule over the last six sessions at each reinforcement-magnitude condition is displayed in Figure 10. This score was calculated by measuring the time to the first response following the insertion into
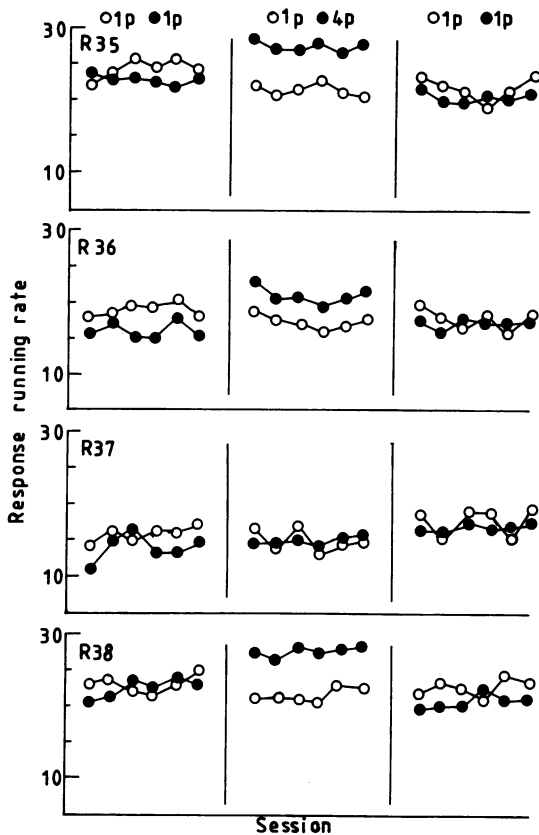
Fig. 9. Results from Experiment 4. Response running rates in both components of the multiple VI 60-s VI 60-s schedule over the final six sessions of each phase for each subject. These scores were calculated by subtracting the postreinforcement pause from the time spent in each component prior to calculating response rate. Open circles = unshifted component, filled circles = shifted component, 1p = one-pellet component, 4p = four-pellet component.
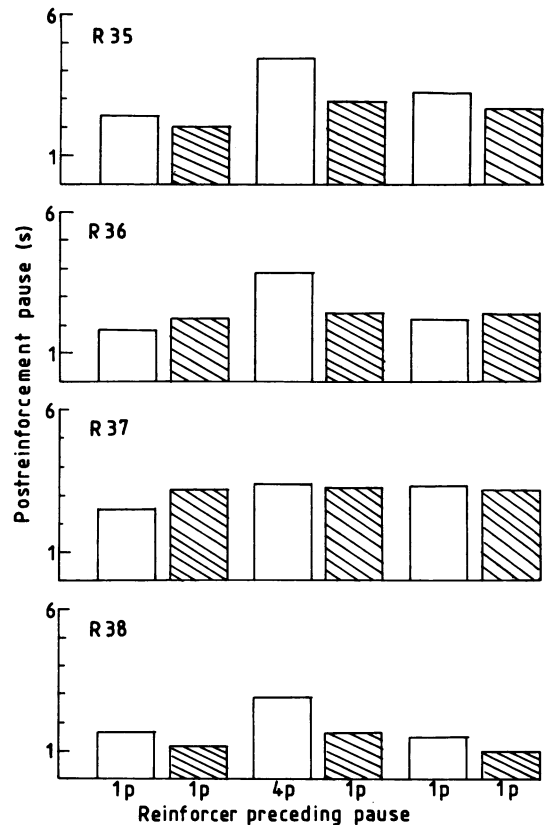
Fig. 10. Results from Experiment 2. Postreinforcement pause for both components of the multiple VI 60-s VI 60-s schedule calculated as a mean for the last six sessions of each phase for each subject. Open bars = shifted component, hatched bars = unshifted component, 1p = one-pellet component, 4p = four-pellet component.

the chamber of the lever associated with a particular component. Inspection of these data from Phase 1 reveals that the postreinforcement pause was similar to the two components. In Phase 2, there was a large increase in the postreinforcement pause following the delivery of the four-pellet reinforcement compared to the postreinforcement pause in that component during Phase 1. There was no increase in the length of the pause following the delivery of the one-pellet reinforcement. On return to baseline, the postreinforcement pause following the changed component was slightly longer than that observed in Phase 1; the postreinforcement pause following the unaltered component was not surprisingly, unaltered.

The present results demonstrate that, when

subjects are exposed to two magnitudes of reinforcement associated with two components of a multiple VI VI schedule, response rates are directly related to the amount of reinforcement received. This is consistent with previous findings using multiple VR VR schedules (Blakely & Schlinger, 1988) and indicates that similar effects occur in both multiple and concurrent schedules with regard to the effect of reinforcement magnitude. These results offer rather more support to an explanation in terms of contrast (Reynolds, 1961) than one in terms of response contingency (Neuringer, 1967). The contrast effect may augment response rates following the delivery of higher magnitudes of reinforcement, an effect that may not be evident if smaller-magnitude reinforcement were not also presented during the same session as the large magnitudes.

GENERAL DISCUSSION

The present report attempted to delineate the situations in which an increase in the magnitude of reinforcement leads to an increase in free-operant response rates and those in which it leads to a decrease in response rate. Experiment 1 demonstrated that an increased magnitude of reinforcement produced a lower response rate on a VI schedule. The detrimental effect on instrumental performance of increased reinforcer amount on a VI schedule was again obtained in Experiment 2, where it was also noted that the same increment in reinforcer size tended to increase response rate on a VR schedule. This result partly replicated a previous study in which increased magnitude of reinforcement generated increased response rates on simple VR schedules (Reed & Wright, 1988).

It has been noted, however, that the results from the VI schedules stand in contrast to several previous reports of the effect of increased reinforcement magnitude on VI schedules. These reports have noted increased rates of response due to increased amounts of reinforcement (e.g., Bradshaw et al., 1978). Given the variety of effects noted on single free-operant schedules, it is clear that a coherent account of such effects needs to focus attention on a number of factors, including the overall rate of reinforcement onto which the change in reinforcer magnitude is imposed and the manner in which reinforcement is defined (see Bradshaw et al., 1981; Herrnstein, 1974, for further discussion). The present results do, however, also indicate the possible importance that the prevailing structure of behavior may have in interacting with the effects of reinforcement magnitude. One interaction consistent with the data from the present Experiments 1 and 2 is that the various magnitudes of reinforcement may differentially strengthen particular patterns of responding emitted prior to its delivery (Carlson & Wielkiewicz, 1976; Hendry, 1962; Reed & Wright, 1988). Thus, on schedules that may reinforce short IRTs (e.g., VR schedules), increases in reinforcement magnitude produce higher response rates. In contrast, on schedules that reinforce long IRTs (such as VI and DRL schedules), increased levels of reinforcement support the emission of these long IRTs and reduce response rate.

Additional processes may need to be invoked to explain the results of increased reinforcement magnitude on two-component schedules. Experiments 3 and 4 demonstrated that, when the reinforcement magnitude is increased for one component of a two-component schedule, the level of responding associated with the large-magnitude component increases relative to the lower-magnitude condition. This effect is the opposite of that noted on simple VI schedules in Experiments 1 and 2 and presumably reflects the operation of an additional mechanism. Neuringer (1967) suggested that the contingency between responding and magnitude was critical in generating performance. However, the fact that similar effects were noted on schedules in which there was a contingency between behavior and magnitude (i.e., the concurrent schedule in Experiment 3) and schedules in which there was not (i.e., the multiple schedule in Experiment 4) suggests that Neuringer's hypothesis is not adequate in explaining the effect on the multiple schedule. A plausible alternative factor is contrast (Reynolds, 1961); the factors responsible for producing contrast may generate a higher rate of response in the component of a two-component schedule associated with a higher magnitude of reinforcement.

The factors responsible for producing contrast would also operate, off course, during exposure to a single schedule. On VR schedules an increase in the magnitude of reinforcement between phases would be expected to produce enhanced responding due to contrast and due to the shaping of short IRTs. However, on a VI schedule these two factors would work in opposition to each other, contrast tending to elevate response rates and the shaping of IRTs tending to depress response rates. The overall effect on response rate may be due to the interaction of these two factors. Such considerations may also help explain the discrepancies between the various studies of reinforcement magnitude on simple VI schedules (see Bradshaw et al., 1981).

These studies, combined with previous data, indicate that the isolation of reinforcement magnitude as a fundamental determinant of behavior may be at best mistaken and in all probability is misleading. Rather than focus on the effect of reinforcement parameters, more attention needs to be directed to the interaction between reinforcement and the prevailing be-

havioral structure at the time of the reinforcer manipulation.

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